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Karst topography and karstification processes in the Eocene limestone plateau of El Bahariya Oasis, Western Desert, Egypt

by

M. M. El Aref, A. M. Abou Khadrah and Z. H. Lotfy, Cairo

with 5 figures, 11 photos and 1 table

Zusammenfassung. Kegelkarst und Cockpits sind die wesentlichen Landformen auf dem eozänen Kalkplateau der El-Bahariya-Oase. Diese Formen entsprechen einem Bildungsstadium des Karstsystems und scheinen sich durch verschiedene Generationen der Auflösung, des Zerbrechens, Zusammenbrechens und der Zementierung entwickelt zu haben. Die zweidimensionalen Streichrichtungsdiagramme zeigen, daß die Verbreitung dieser Kegel durch das Strukturmuster des Kalkplateaus kontrolliert wird.

Die Kalkkegel sind normalerweise durch Terra rossa bedeckt und bestehen aus Intrakarst-Ablagerungen klastiscben Materials und cbemischen Ausscheidungen. Die Klastika wurden durch das Zerbrechen des Anstehenden erzeugt und bestehen aus Fragmenten unterschiedlicher Korngröße, vom Ton bis zu großen Blöcken. Sie sind eingebettet in dichte Ockerlehme oder erdiges Material und im allgemeinen durch chemische Neubildungen zementiert. Dieser Zement entstand während des Wachstums von Dolomit, Süßwassercalcit, Feuerstein und Evaporiten, zusammen mit Eisen und Manganoxiden und Baritkristallen.

Es wird ein genetisches Modell aufgestellt, in dem die paläoklimatischen Bedingungen, die wir in dem Arbeitsgebiet nach dem Eozän annehmen, berücksichtigt werden.

Summary. Conekarst and cockpits are the main landforms characterizing the Eocene limestone plateau of El-Bahariya Oasis. These features represent an evolution stage in tbe karst system and seem to be developed through different generations of dissolution, brecciation, collapsing and cementation. The two dimensional strike frequency diagrams show that the distribution of these cones is controlled by the structural pattern of the limestone plateau.

The karst cones are usually encrusted by terra rossa and consist of intra-karstic sedimentary fillings of clastic and chemical precipitates. The clastics were produced by brecciation of the country rocks and include fragments of different grain sizes ranging from clay to boulders and blocks. They are embedded in ochres or earthy products and are usually cemented by chemical minerals. The cement is formed during growth processes of dolomite, fresh water calcite, chert and evaporite minerals together with iron and manganese oxides and barite crystals.

A genetic model is introduced reflecting the paleoclimatic conditions which are believed to be imposed on the area under consideration during the post-Eocene time.

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Résumé. Le kegelkarst et le karst à cockpit constituent les paysages essentiels du plateau calcaire des oasis El-Bahariya. Ces formes correspondent à un stade de formation du système karstique et semblent résulter de divers cycles de dissolution, de découpage, d'effondrement et de cimentation. Les diagrammes de répartition en plan montrent que la distribution de ces cônes est contrôlée par la structure du plateau calcaire.

Les cônes karstiques sont généralement encroûtés par la terra rossa et entre ces cônes on trouve des remplissages sédimentaires intrakarstiques de débris et de concrétions. Les débris furent produits par bréchification des roches régionales et comprennent des fragments de différentes classes granulométriques de l'argile aux blocs. Ils sont inclus dans des produits ferrugineux ou terreux et sont habituellement cimentés par des minéraux néoformés. Le ciment est formé pendant les processus de croissance de dolomite, de calcite d'eau douce, de chert et de minéraux d'évaporite en même temps que des oxydes de fer et de manganèse et des cristaux de barite.

Un modèle génétique est présenté pour refléter les conditions paléoclimatiques qui sont supposées avoir dominé dans la région considérée pendant la région considérée pendant la période post-Eocène.

Introduction

The northeastern part of the limestone plateau of El Bahariya Oasis is the subject of the present geomorphologic study. This area attains to represent a typical karst landscape.

The study area lies between longitudes 28° 54′ to 29° 12 E′ and latitudes 28° 18′ to 28° 48′ N bounding the scarp face of El Bahariya depression. It is mainly covered by limestones of Early, Middle to Late Eocene ages. Stratigraphically, the Eocene limestone was the subject of study by many eminent authors, e.g.; El Shazly 1962, Said, 1962, El Akkad & Issawi 1963, Said & Issawi 1964 and Basta & Amer 1969.

According to the classification of El Akkad & Issawi 1963 and Said & Issawi 1964, the lithostratigraphic units of the carbonate rocks in the study area include the following formations arranged from top to bottom:

El Hamra Formation (Upper Middle to Upper Eocene)
Quazzun Formation (Upper Middle Eocene)
Naqb Formation (Lower Middle Eocene)
Farafra Formation (Lower Eocene)

Saad, 1979 reviewed the structural work done on the area under consideration. Normal faults and folds are the predominant structural elements. The faults extend in a NE-SW, NW-SE and E-W directions. The folds are grouped into NE, NW and NNE trends.

Surficial regional karst landforms

Cockpit karst (kugelkarst or Halbkugel karst) and its evolutional stages are the main conspicuous morphologic landforms characterizing the eastern plateau limestone of El Bahariya Oasis. The general landscape is dominated by residual isolated or connected cone hills combined with star-shaped depressions or cockpits (Lehmann 1936, 1954a, b and Sweeting 1958). The karst morphology of the study area constitutes the following progressive types grading from typical mature cockpit karst terrains down to the final peneplained areas: 1) mature cockpits, 2) degraded cock-

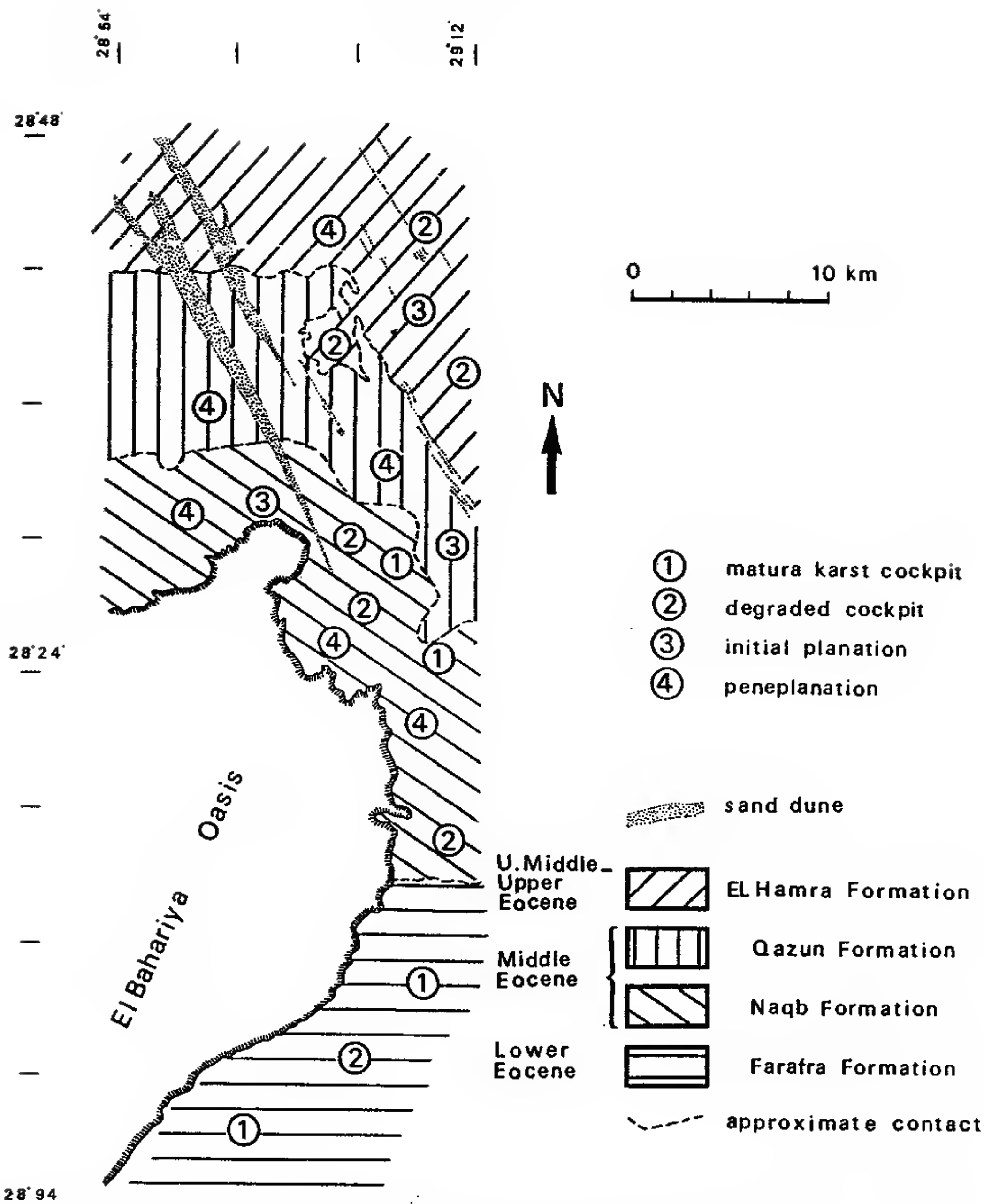

Fig. 1. Distribution map of the different karst stages in the northeastern limestone plateau of El Bahariya Oasis.

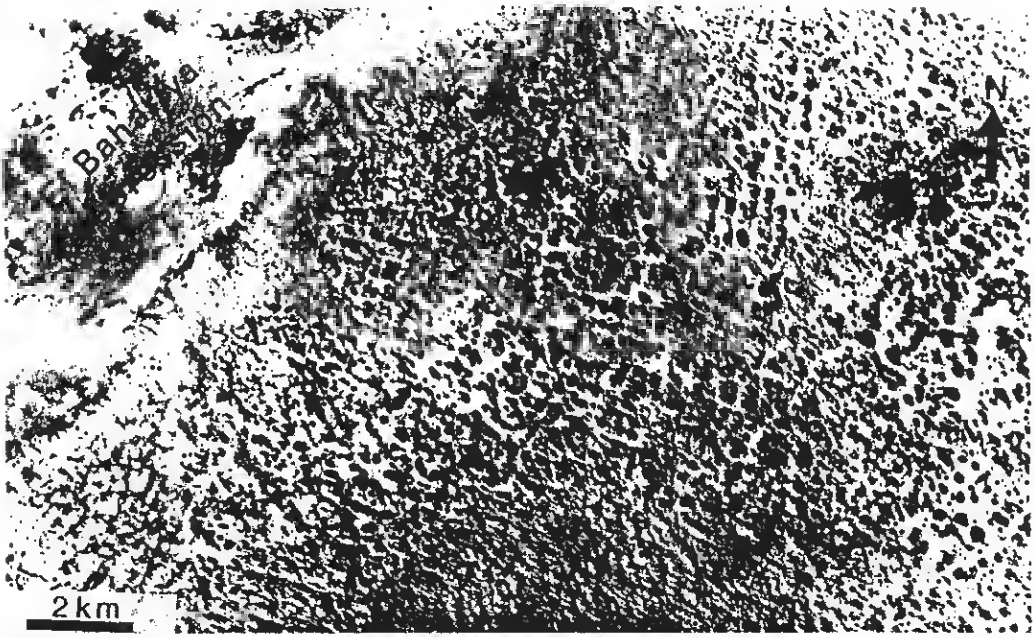

Photo 1. Aerial photograph of the mature cockpits of stage IV in fig. 5, Farafra Formation.

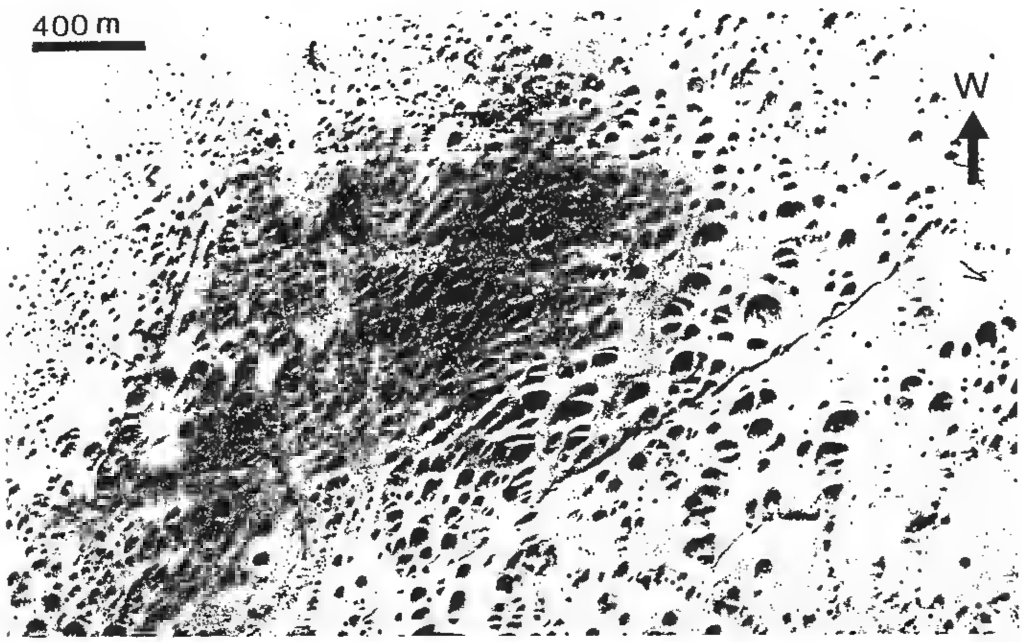

Photo 2. Aerial photograph of the degraded cockpits of stage V in fig. 5, Naqb Formation.

Photo 3. Field view of the symmetrical and asymmetrical cone hills of stage V in fig. 5, Naqb Formation.

pits (SWEETING 1958); 3) initial stage of planation and, 4) peneplanation stage. The intimate relation in the observed morphologic features reflects the regional evolutional trend of karstification arising through: a) change in the shapes and degree of arrangement of the elevated hills, b) reduction of the relief and rolling of the hills, c) wideness and shallowing of the surrounding cockpits and, d) development of peneplained surfaces and flat floors. These karst units are developed in different geographic localities in the study area (fig. 1 and photos 1–3). The mature cockpits are commonly prevailing in the central and southern parts of the area, while degraded cockpits associated with the other advanced morphologic forms are well represented in the northern limestone plateau.

The mature cockpits are essentially composed of elevated, steep and large hills. The hills are closely spaced and separated by narrow and considerably deep star-shaped depressions. The degree of the hillsides and cokpit slopes ranges from 30°–50°. The hills are of concial or rectangular shapes. Some are of flat topped surfaces forming buttes. The hills rise from 39–100 m in height. The elevations of these hills are generally decreasing towards the NE and SW directions of the eastern scarp of El Bahariya Oasis (photo 1). The hills show also marked reduction in their elevations in the direction of ordering degraded cockpits or peneplained areas. The degraded cockpits include wide distributed isolated rolled hills, smaller in size than those of the mature cockpits, up to 150 m wide. Their elevations range between 30 m to tens of centimeters above the floor. The residual hills are usually of cone, domal or elongated shapes with rounded, oval or ellipsoidal outlines (photo 2). The long axes of the elongated hills follow the NW-SE direction. The cockpits become wider

and shallower than in the mature cockpits and are usually characterized by concave floor pattern. The slope angles of these cones and the enclosed cockpits may be symmetrical or asymmetrical ranging from 10° to 30°. The longest slopes of the asymmetrical cones generally extend towards the SE direction. The development of the asymmetric arrangement of the cones may depend upon the amount of dip of the limestone or the direction of the solution and weathering. The small sized cones show signs of decreasing in their slope angles comparable with the bigger cones (photo 3). In the Naqb Formation, the slopes of the cockpits are usually encrusted by silcrete and red to violet residual clayey material "terra rossa". The surrounding basins are commonly filled by alluvial sediments and scree. In El Hamra Formation, the depressions are filled by wind blown sand, debris and clayey products.

In the mature and degraded cockpit terrains, the residual hills and the associated cockpits are commonly arranged in rectilinear alignment forming "gerichteten" (Lehmann 1954 and Wissmann 1954) or directed karst (photos 1 and 2). Connection of some cones may distributed in straight gently curved or irregular lines exhibiting karst linear ridges of sawtooth configuration. Directed gradual decreasing in the elevation of the cones characterize the linear ridges. In some instances, the cone hills are distributed in concentric adjustment, where relatively small cones surround bigger ones. The karst cones are commonly dissected by sparsely steep joints and deflected into semilunar shapes. As a result of advanced rill wash erosion, the original preexisting cone hills are gradually separated into concentric cresentric forms.

The progressive subaerial deterioration of the cockpit evolution is represented by the development of initial planation stage. The karstic areas of this type are characterized by the occurrence of widely spaced and less conspicuous cone hills scattered in nearly peneplained surface. This karst stage is mainly displayed in the Qazzun Formation with pronounced corestone boulders on the floors and is partially recognized in the Naqb and El Hamra formations. In the final peneplanation karst stage, the hilly configuration is mostly absent and the relief of the limestone plateau becomes nearly flat. The flattened surfaces are usually covered by wind blown sand, scree and residual debris. They include shallow basins filled with playa deposits or alluvial sediments.

Structural control

An area of about 300 km^2 covered by the Naqb Formation has been selected for quantitative lineament measurements. Two dimentional azimuth frequency diagrams (i.e. Rose diagram) for 19 sectors are plotted in fig. 2. The regional pattern of the represented lineaments is indicated by the following categories arranged in decreasing order of abundance: N-S, NW, NE and E-W trends.

The observed intersectional structural pattern distinctly controls the arrangement pattern of the cone hills and cockpits and discloses its great role in the development of the karst morphology. These structural weak planes seam to be the fundamental factor guiding the increase of the limestone permeability and the direction of the gulley erosion of paleocentripetal streams.

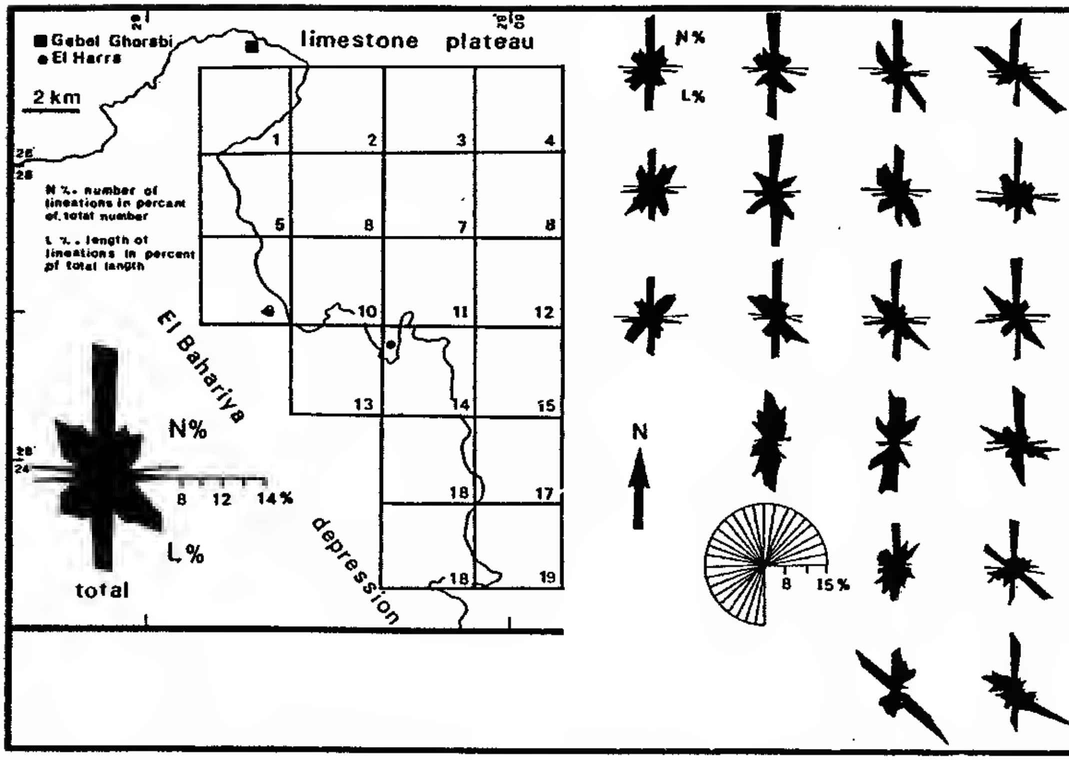

Fig. 2. Location map of the selected sectors and the strike-frequency diagrams (i. e. Rose-diagram) of their lineations; limestone plateau, El Bahariya Oasis.

Small scale karst features and karst sediments

Detailed systematic investigations on the described regional elevated landforms revealed that they include megascopic and microscopic different solution karst features consisting of intra-karstic sediments. Karst features and the associated sediments are illustrated in figs. 3 and 4.

The revealed megascopic solution features are represented mainly by the development of vertical and horizontal surface karrens, crevices, fractures, small channels and cavities. The fractures and the channels are of different shapes, diameters and directions. They form usually anastomosing patterns around larger scale negative opening features and display an enormous role in the transmission of surface solutions through the outlets into the cavities. The cavities range between 3 to 20 m in diameter. The roofs and the walls of these cavities are commonly crackled, characterizing the beginning of collapsing. Small subsidence dolines and holes have been also recognized in the available cross cutting faces of the limestones plateau. The former is introduced during gravitional sinking of collapsed limestone layers into deeper openings, up to 7 m in diameter (fig. 4A). The solution holes are usually of vertical orientation, up to 2 m in width and may extend downwards untill the horizontal

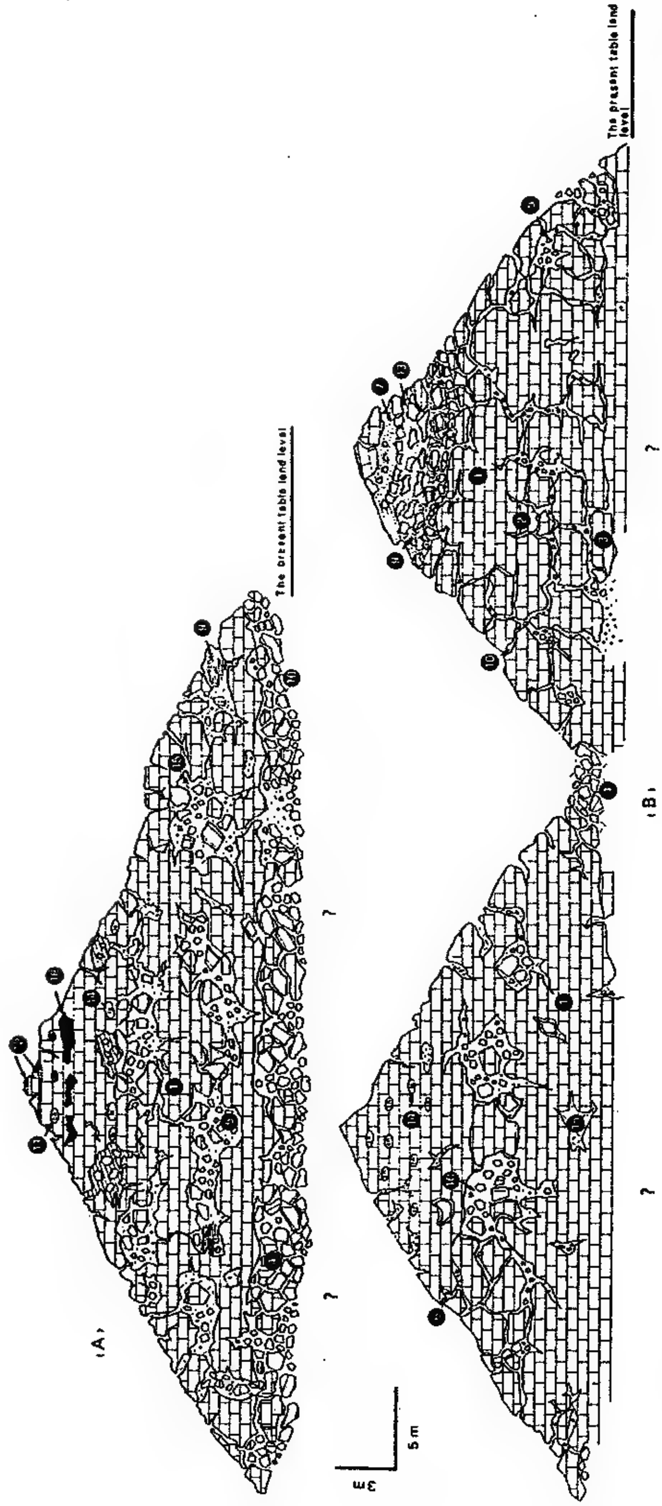

Fig. 3. Schematic representation of the composition of isolated karst cone (A) and cones with cockpit (B); Naqb Formation. The data are based on detailed stratigraphic mapping of different cones (explanation in fig. 4).

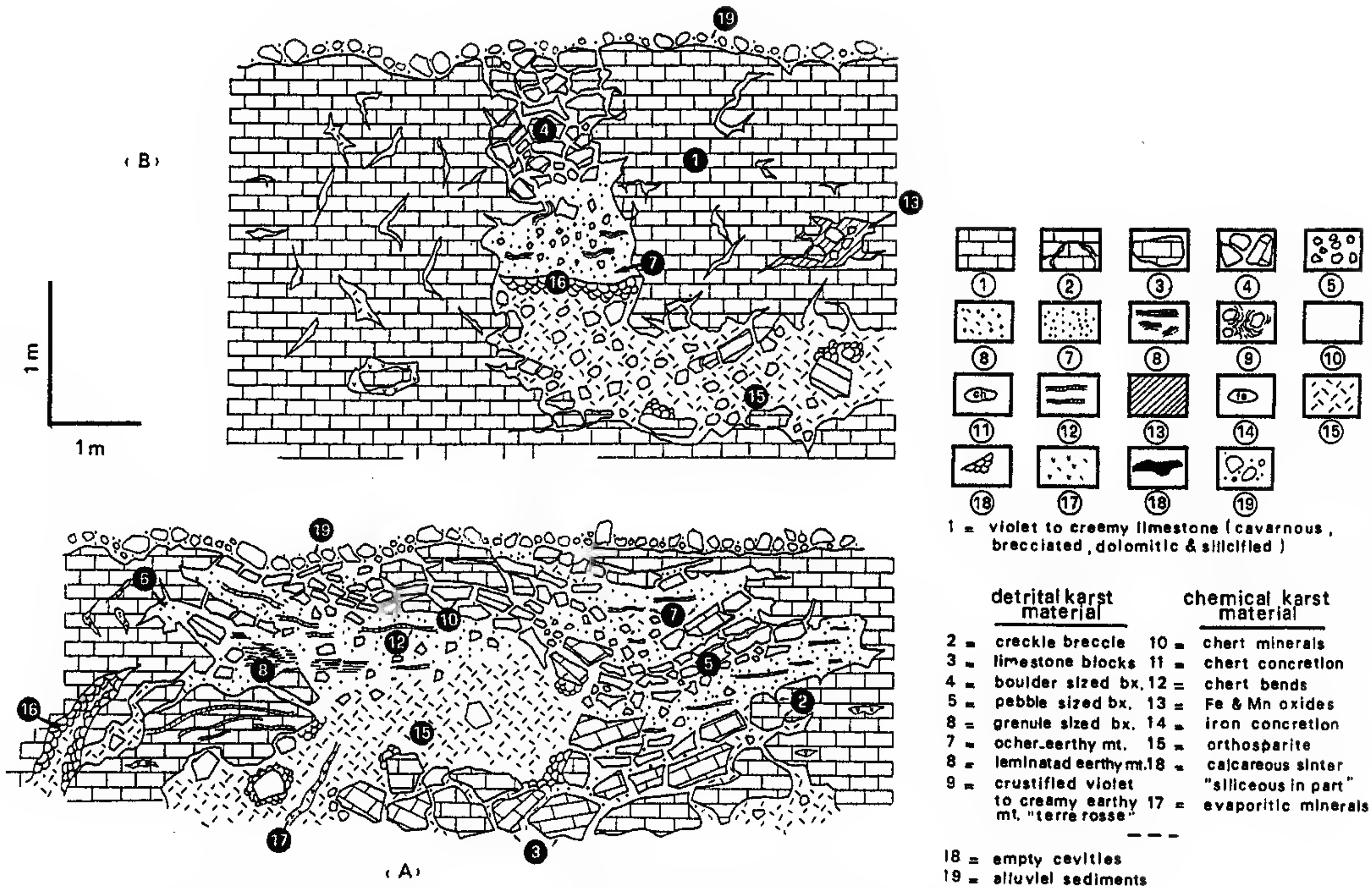

Fig. 4. Schematic representation of karst hole (B) and small scale subsidence doline (A); Naqb Formation.

Photo 4. Handspecimen photograph showing calcareous sinter duricrust capping silicified and brecciated substrata, the Naqb Formation.

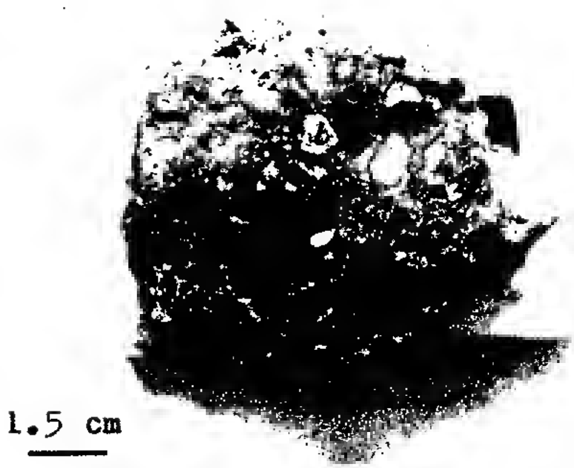

Photo 5. Red to violet clayey earthy materials (terra rossa) including limestone breccia fragments, the Naqb Formation.

Photo 6. Polished slab showing silcrete duricrust capping silicified and brecciated limestone substrata and includes limestone breccia fragments, the Naqb Formation.

cavities (fig. 4B). These solution features are mostly observed in the Naqb and the Qazzun formations and are slightly distributed in El Hamra Formation.

Under the microscope, solution veinlets and cracks represent the earlier episode of the karst dissolution. Collections of these veinlets tend gradually to develop initial microbrecciation or microscale breccia. The original carbonate of the chambers and chamberlets of the mega- and microfossils are ultimately dissolved giving rise to fossil cavities.

The described megascopic and microscopic solution features are mainly fossiled, being filled by intra-karstic sediments. Moreover, the karstic limestones are commonly mantled by "terra rossa", silcrete and calcareous-siliceous sinter duricrusts. The duricrusts occur in variable proportions on the different morphologic forms and the stratigraphic units. Terra rossa and silcrete duricrusts mostly exist in tbe Naqb Formation, wbere calcareous-siliceous sinter is commonly prevailing on the upper surface of the Qazzun and El Hamra formations. They usually include limestone breccia fragments and fill veinlets and cracks of the brecciated substrata (photos 4–6).

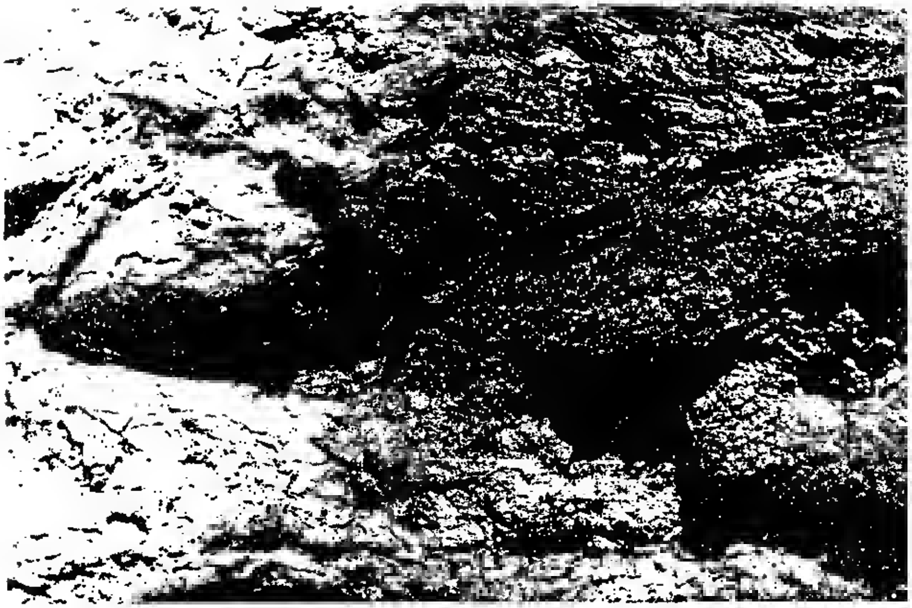

Photo 7. Field photograph of spheroidal concentric weathering, El Hammra Formation.

The intra-karstic sediments include, clastic, chemical and organic products. The clastic filling materials consist mainly of autochtonous and allochtonous sediments. Collapse dolomitic and silicified limestone breccia fragments of block, cobble, boulder, pebble and sand sizes constitute the composition of the autochtonous sediments. They are angular to subangular denoting short transportation away from the roofs and the walls of the enclosing solution features or may have been produced in situ during different stages of brecciation. The allochtonous filling consists of transported highly silicified limestone or chert nodules, subrounded to rounded and of different grain sizes. The autochtonous and allochtonous fragments are usually cemented by chemical precipitates and/or embedded in finer clayey and red earthy materials, calcareous mud and red and yellow ochres.

The chemical karst cement consists mainly of silica, carbonate, sulphate and halide minerals with iron and manganese oxides. The organic products include carbonaceous matter with algal filaments deposited between the clasts. Residues of organic remaines are distinctly associated with the chemical sediments especially in the sinters. The residual soily materials (terra-rossa) also include root molds.

The karstic limestones and the karst sediments exhibit the following characteristic megascopic textures:

(1) Spheroidal or concentric weathering (entirely separated corestone or "Kernell"; Linton 1955) characterizing the uppermost limestone layers in which shells of residual materials are successively separated from jointed limestone boulders and gravels. This feature is mainly recognized in El Hamra and the Qazzun formations. The end products of this feature form accumulations of shells of clayey material around marly limestone conglomeratic fragments in El Hamra Formation (photo 7)

Photo 8. Most resistant highly silicified limestone concretion (corestone), the Qazzun Formation.

or most resistant highly silicified limestone concretions in the Qazzun Formation forming corestone (photo 8).

(2) Diffusion front pattern along fractures of the karstic limestone was formed during rhythmic precipitation from diffusing solutions in the capillary spaces of the rocks. In the ultimate diffusion stages, the fronts consist of successive and cyclic layers of calcareous mud and of concavo-convex outlines. The layers exhibit gradations of pink, red brown and deep brown to violet colours. Profile of microprobe analysis (table 1) revealed that the colouration of these layers may be introduced by the increasing of the Fe concentration with slight influence of Mn. This fabric is assumed to be genetically related to the diffusion or confluent insurgences hydrolo-

Table 1 Microprobe analysis of representative profile in the coloured limestone, Naqb Formation.

	Pink coloured limestone layer			Red brown limestone layer			Violet limestone layer		
	1	2	3	1	2	3	1	2	3
CaO %	29.71	29.39	29.88	29.74	30.50	31.04	27.97	29.94	29.31
MgO %	21.81	21.35	21.95	17.59	20.49	18.55	17.17	18.64	18.20
FeO %	0.02	0.07	0.02	5.63	1.36	3.48	7.44	4.20	5.17
MnO %	0.04	0.02	0.03	0.20	0.20	0.19	0.24	0.34	0.32
CO_2 %	47.15	46.2	47.43	46.10	47.25	46.85	45.40	46.61	46.22
Total	98.73	97.25	99.31	99.26	99.80	100.11	98.22	99.73	99.22

gic processes of the parent karst solutions which was described by Sweeting 1973 and Mylroie 1984.

(3) Crackle breccia characterizing the walls of the opening features and grading gradually to form collapsing features.

(4) Caverneous textures.

(5) Cockade structures formed by the encrustation of the residual clayey materials and the calcareous muds or the chemical cement around the collapsed breccia fragments.

(6) Pisolitic concentric texture characterizing the earthy residuals and the ochres.

(7) Rhythmic deposition and crystallization of fine clasts and chemical sediments (photo 9).

(8) Fine alternative laminations of fine clasts and calcareous mud (photo 10).

Photo 9. Cyclic alternative lamination of fine clasts and orthosparite.

(9) Layering structures recognized by the formation of chert bands and local normal or graded bedding arrangement of the clasts.

(10) Isolated concretions or nodular forms embedded within the karstic rocks and consist either of chert, iron and maganese oxides, calcite or earthy products.

(11) Crustification textures consisting of karst sediments deposited on the walls and roofs of the solution features or characterizing the surficial duricrusts.

On the microscopic scale, the composition and ordering of the cement minerals reflect their environmental conditions. The internal morphologic patterns of these minerals indicate their growth directions and declare their paragenetic sequence.

The silica minerals occur as fibers or spherulites of length slow chalcedony, microcrystalline quartz grains, coarse mosaic quartz and pyramidal idiomorphic quartz crystals (photo 11). The length slow chalcedony characterizes the sulphate rich environments of semi-arid alkaline soils and is considered to be valuable paleo-

Photo 10. Polished slab of collapsed breccia fragments embedded in fine laminated clasts and calcareous mud.

climatic indicator (FOLK & PITTMAN 1971). It is observed in the karst environment (ZUFFARDI 1976). The carbonate minerals are represented by dolomite and orthosparitic calcite. The latter commonly forms bladed elongated crystals, zoned grains or blocky masses of white, rose and dark grey to black colours. Gypsum and anhydrite with or without barite are the main evaporitic minerals. Halite crystals usually fill the remaining spaces of the solution features.

The chemical cement encrustation fill asymmetrically or symmetrically the open spaces. In the former case, the cement exhibits microstalactitic and meniscus textures, while in the latter case, successive encrustations are formed by multimonomineralic layers. The earlier layer directly deposited on the walls of the solution features usually consists of dolomite and is followed by silica of different morphologic patterns. The youngest layers towards the center of the open spaces are usually represented by orthosparite. These layers may be intercalated by thin laminae of iron and manganese oxides and/or carbonaceous matter. The silica and the orthosparite are often arranged as elongated bladed crystals, with gradual increase in their grain size perpendicular to the base of the successive crusts. They exhibit idiomorphic terminations and chevron growth patterns towards the centers of the open spaces. In the centers of these open spaces, the cement minerals show equigranular mosaic texture. Evaporitic minerals usually fill the remnant primary spaces of the solution features.

The different megascopic and microscopic textures of the karst sediments reflect a depositional and diagenetic processes in vadose and phreatic environments. The vadose environments is elucidated by the formation of the microstalactitic and meniscus textures, on the other hand, isopachous and blocky mosaic fabrics denote the phreatic environment (TUCKER 1981). Rhythmic cyclic alternations of clastics and chemical products represents the depositional regime. The diagenetic processes are encountered by progressive crystallization generations of dolomite, silica, calcite and evaporites with iron and manganese oxides respectively. The development of these successive crystallization generations are obviously controlled by the physiochemical conditions of the medium (pH, Eh, ion concentration, solubility, ... etc.). Two diagenetic systems are suggested to explain the mechanism of the differentiation of these crystallization generations. Open diagenetic system is responsible for the formation of repeated multicrusts in surficial open spaces (formation of crustified duricursts) and closed diagenetic system capable of filling of the closed open spaces.

Conclusion and hypothetic genetic model

The northeastern part of the limestone plateau of El Bahariya Oasis represents a typical karst landscape. The present karstic landform can not be explained in a simple way. The development and the evolutional trend of the karst could be achieved through simultaneous attentive respects of multicontroling factors. Paleoclimatology, structure, lithology, and paleotopography seem to be the main elements responsible for the modification of the karstification in the area. The karst cycle is mostly favourable for erosion, dissolution, transformation, transportation, subsidence, collapsing, redeposition and diagenetic processes.

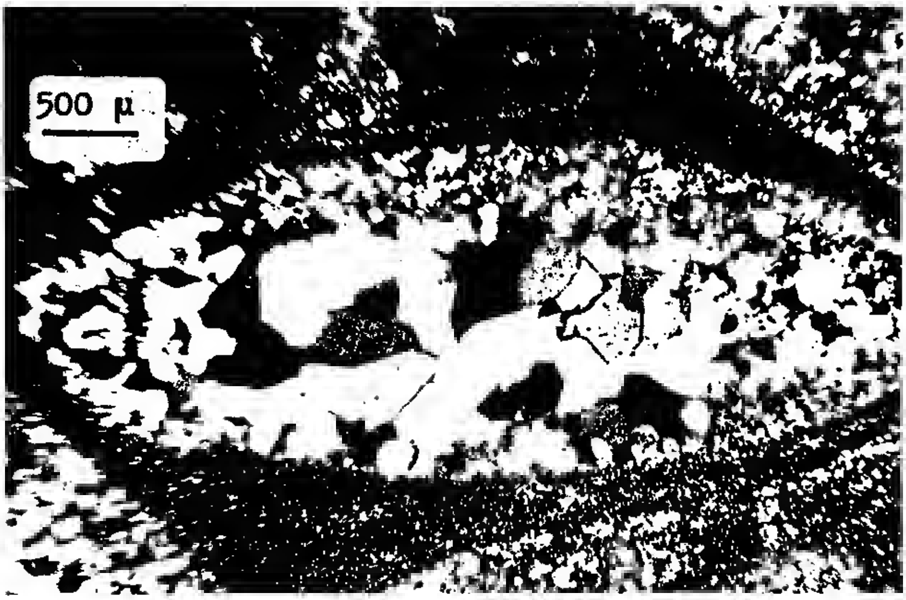

Photo 11. Photomicrograph of preserved nummulitic cavity symmetrically filled with chert. Notice the increasing of the quartz grain size towards the center of the cavity (crossed nicols).

The general landscape is dominated by regional cone or cockpit karst type associated with local solution features and karst sediments. The regional evolutional morphologic trend of the cockpit karst arose through the development of the following progressive stages: mature cockpit, degraded cockpit, initial planation and peneplanation. The cockpits constitute a spectacular type of karst topography developed in humid-tropical climates (Sweeting 1973, Faniran & Jeje 1983 and White 1984).

Considering the studies of Simons 1984, the karstification processes of the study area seem to be developed during the Oligocene Epoch. He mentioned that the Fayum region and the surrounding areas were characterized by high seasonal rainfall and forest vegetal cover during the Oligocene time.

The arrangement of the present cone hills and cockpits is distinctly controlled by the intersectional structural patterns of the study area. These structural weak planes seem to be the fundamental factor guiding the limestone permeability and the direction of the gully erosion.

Contemporaneously with the development of the regional karst forms, local megascopic and microscopic solution features associated with karst sediments are prevailing. The solution features include karrens, crevices, fractures, channels, cavities and holes. The karst sediments are displayed by the formation of terra rossa, silcrete and calcareous-siliceous sinter duricrusts capping the karstic limestones or by intra-karstic clastic, chemical and biogenic sediments filling the solution open spaces. The karst sediments exhibit different megascopic and microscopic textures denoting depositional and diagenetic processes in vadose and phreatic environments.

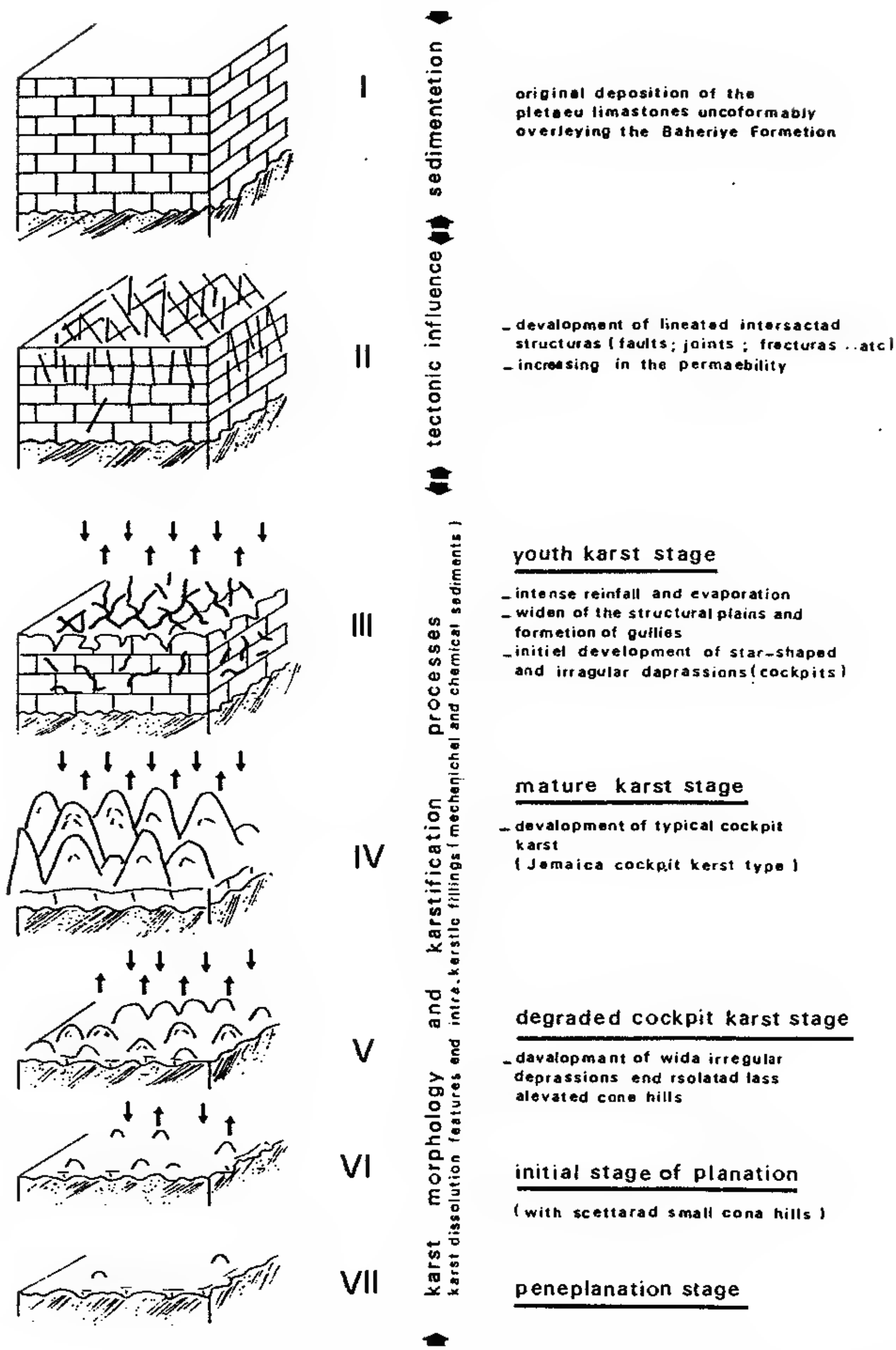

Fig. 5. Schematic genetic model of the karstlandforms of the northeastern limestone plateau of El Bahariya Oasis.

The diagenetic processes are encountered by successive crystallization generations of dolomite-silica calcite and evaporites with or without iron and manganese oxides. Closed and open diagenetic systems are suggested to explain the mechanism of the differentiation of the crystallization generations of these minerals.

The variable distribution of the regional karst landforms, the small scale solution features and the karst sediments in the different stratigraphic units of the study area are most probably controlled by the original lithologic characters of the carbonates and the paleotopography of the plateau.

The systematic field observations and megascopic and microscopic examinations lead to sugget a hypothetic genetic model (fig. 5) for the post depositional karst history of the plateau limestones. It elucidates the evolutional trend of the karst landscape and the associated karstification processes.

The karstification processes and the related karst sediments have to be considered in the lithostratigraphic classification of the plateau limestones in order to differentiate the subaerial younger sediments from the original marine limestone deposits.

The genetic relation between the present karst morphology and: a) the origin of El Bahariya depression; b) the origin of the iron ore deposits of El Bahariya Oasis and, c) the continental sediments of the Radwan Formation will be given in a later comprehensive study.

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Addresses of the authors: M. M. El Aref and A. M. Abou Khadrah, Cairo University, Faculty of Science, Geology Department, Cairo, Egypt; Z. H. Lotfy, Ain Shams University, Faculty of Education, Natural History Department.